gross weight is within the required limits. The work load should be budgeted so that the evaluator has enough time available to properly perform the test and still aviate, navigate, look for traffic, etc. Ideally, the test should be performed in a dual piloted aircraft, allowing one pilot to concentrate on the test while the other flies the aircraft. With two pilots, proper crew coordination is an important safety concern.

Where airborne targets are used, a face to face brief prior to the test must be required. The procedures for each test should be understood by all participants. A procedure to immediately terminate each test whenever any participant notices any unsafe condition must be thoroughly briefed.

The test systems and safety of flight systems required for each test and target aircraft must be outlined and used as a criteria for test cancellation. It is much cheaper to cancel a test while on the ground than in the air.

Time should be set aside during the planning stage of any test for all the participants to gather and discuss the safety of flight issues. A simple but effective procedure is to reserve a short period of time (perhaps a half hour) during the planning process for all participants to discuss possible safety issues, system failure modes or accidents that could occur and to plan how to react in their eventuality. A half hour of planning is a small price to pay for a safe test evolution.

7.0. CASE STUDY

7.1. INTRODUCTION

The previous sections provided a discussion of how to perform basic flight tests on air-to-ground radar, air-to-air radar, navigation, electro-optical and stores management set systems. A basic assumption for the development of these techniques was that a minimum of instrumentation was available outside of the production aircraft's complement of systems. In implementation this is often the case. Scheduling or cost may limit the amount of instrumentation and support available to perform a test. Additionally, as explained in Chapter 1, even when instrumentation allows extensive data collection, the test techniques are often similar or even identical and the rough, hand-held data is still collected. The data is then available for immediate use, without the requirement for extensive data reduction and formatting usually needed after automatic collection. This immediate feedback is used for adjusting of the next test evolution or as a means for focusing the data reduction effort on test events which are critical.

The following case study is presented to illustrate the implementation of the thought process used in developing the test procedures outlined in the previous sections. This case study is a straight-forward application of a couple of the test procedures outlined above without the addition of extensive instrumentation requirements. The scenario is contrived but illustrates how the techniques above can be used to provide quick and supportable answers to real world questions where extensive preparations and instrumentation are not possible.

7.2. AIR-TO-GROUND RADAR RESOLUTION USING A MINIMUM OF INSTRUMENTATION

7.2.1. Background

This case study is intended to illustrate how the techniques outlined in the previous sections may be applied to quickly answer a question about the technical performance of a radar. The scenario is based upon a fictional United States Navy F/A-XX aircraft with the APG-XX radar. The APG-XX radar has been developed as an avionics upgrade to the F/A-XX aircraft. The Navy program manager, responsible for the development and procurement of the upgrade, (PMA-XXX) has heard via his program contacts that the APG-XX radar is "not even close" to meeting the air-to-ground resolution specification. A specification is a design requirement imposed upon the contractor as a means of defining the minimum acceptable standards for the system under development. PMA-XXX called your department head and ordered a "quick test" to determine the air-to-ground range and azimuth resolution of the radar. You have been assigned as the project engineer.

The contractor has been prompted by PMA-XXX to make the back seat of the single prototype of this two seat strike fighter available tomorrow to do a quick evaluation of the air-to-ground radar resolution as a "piggy back" test on a contractor evaluation. The aircraft is currently in the custody of the contractor as the contractor engineers interactively develop the radar. The contractor has further restricted your evaluation to 30 minutes. Data cards are required so that the project test pilot can leave for the contractor facility in four hours.

As mentioned frequently in this book, an in depth knowledge of the system is essential to the development of a good test. Here, a condensed description of the radar is provided, including only those facts germane to the test design process.

7.2.2. The Test Article

The APG-XX radar has three modes of operation, including REAL BEAM MAP, DBS 1 and DBS 2. In the REAL BEAM MAP mode, the transmit pulse waveform has a pulse width of 0.764 μsec at a 40 nm range scale or less, uncompressed. In the 80 to 40 nm range scale, the pulse width is 2.29 μsec, uncompressed. The antenna beam width is 1.3° horizontally and is spoiled vertically. The display resolution is 75 pixels per inch and the range scales available include 80/40/20/10 nm with automatic downscale available as the aircraft approaches any point which is selected by the geostable cursors.

In the DBS 1 mode, the pulse width is 0.306 μsec, uncompressed at all DBS ranges. The beam width is the same as the REAL BEAM MAP mode beam width and the DBS ratio is 10. The display resolution is the same as in the REAL BEAM MAP mode and the display scale is a 10 nm by 30° B scan format. The maximum range is 40 nm in DBS 1 and the DBS notch width is 7°. In the DBS 2 mode the pulse width, beam width, DBS ratio, display resolution, DBS notch width and maximum DBS range are the same as in DBS 1. The only difference between DBS 1 and DBS 2 is that the DBS2 display is a two fold "blow up" of the DBS display making the DBS 2 display scale 5 nm by 15°.

7.2.3. Theoretical Resolution

In developing the test scenario, it is important to first bound the test parameters by the maximum theoretical limits, and therefore make best use of the test time. The theoretical azimuth and range resolution limits are thus required. The theoretical resolution may be limited by either radar performance or the display resolution. The amount of time that a radar wave requires to travel one nautical mile is defined in Chapter 2 and repeated below in equation 33. The pulse width is then used to calculate the theoretical range resolution of the radar in all three air-to-ground modes.

$$\begin{gathered}
\textit{Radar Mile}=12.36\frac{\mu sec}{nm}\\
\textit{Real Beam Map>40nm Scale:}\\
(2.29\mu sec)\left(12.36\frac{nm}{\mu sec}\right)\left(6000\frac{ft}{nm}\right)=1112\ ft\\
\textit{Real Beam Map<40nm Scale:}\\
(0.764\mu sec)\left(12.36\frac{nm}{\mu sec}\right)\left(6000\frac{ft}{nm}\right)=371\ ft\\
\textit{DBS 1 and 2 (same PW):}\\
(0.306\mu sec)\left(12.36\frac{nm}{\mu sec}\right)\left(6000\frac{ft}{nm}\right)=148 ft
\end{gathered} \qquad (33)$$

Examining the results, it is important to note that the theoretical range resolution is independent of the range to the target; however, the aircraft must be close enough to the range resolution array targets to allow detection of the individual elements of the array. The array may actually include elements of several different radar cross sections and so the evaluator must be aware of the possibility of detecting some elements of the array at different maximum ranges independent of the range resolution characteristics of the radar under test.

Figure 24 illustrates the calculation of the theoretical azimuth resolution of the radar. The azimuth resolution is dependent upon the beam width of the radar antenna and upon the limitations of any schemes designed to improve the azimuth resolution such as in the DBS mode, as outlined in Chapter 2. Two values are significant. First, the radar angular resolution is required. For the Real Beam Mode, this value is equal to the beam width of the radar, which is 1.3°. In the DBS modes the angular resolution is equal to the beam width divided by the DBS ratio. The DBS ratio for the sample radar system is 10 for both the DBS 1 and DBS 2 modes and so the DBS 1 and 2 modes angular resolution is 0.13°. As outlined in Chapter 2, the azimuth resolution array is composed of fixed ground radar reflectors and so the angular resolution value must be interpreted in terms of distance over the ground. The most useful value is the theoretical range at which it is expected that a pair of resolution array targets of known separation will be distinguishable, or break out, as two distinct targets, defined as R_b. This value is calculated as in equation 34.

$$R_b=\frac{S}{\tan(\theta)} \qquad (34)$$

R_b=*target range at breakout*
S=*across axis target separation*
θ=*angular resolution*

Figure 25 is a diagram of the fictional resolution array. The azimuth resolution targets are at the top of the T shape. The widest azimuth target separation of 600 feet in figure 26 is applied to equation 34 for the case of the Real Beam Mode and then for the DBS mode to get equation 35. Table VII shows the results of similar calculations made for all the radar modes and for the three azimuth resolution target separations of 600, 300 and 100 feet.

Real Beam Example:
S=600 *ft*, θ=1.3°

$$R_b=\frac{600\ ft}{\tan(1.3^\circ)}\frac{1}{\left(6000\frac{ft}{nm}\right)}=4.4\ nm \qquad (35)$$

DBS Example:
θ=1.3°, *DBS Ratio*=10

$$R_b=\frac{600\ ft}{\tan\left(\frac{1.3^\circ}{10}\right)}\frac{1}{\left(6000\frac{ft}{nm}\right)}=44\ nm$$

The radar design provides one set of theoretical resolution limits. The display also has resolution limits. The most restrictive of the two sets of limits is the true theoretical resolution limit for the total system. The display measures six inches across and six inches high for a total of 36 in^2. The display resolution is 75 pixels per inch in both directions. In the Real Beam Mode of operation, the possible range scales include 80, 40, 20 and 10 nm in both directions. In DBS 1, the B scan format display scale is 10 nm by 30° and in DBS 2 the scale is 5 nm by 15°. Figure 26 illustrates the implications of these values where it is noted that in theory, two targets must be separated by at least one pixel to be distinguishable on the display. In practice, more pixels of separation are typically required; however, this conservative limit suits our purposes.

Equation 36 is an example calculation for the separation over the ground of two pixels on the display for the Real Beam Mode, 80 nm range scale display. This calculation was repeated to develop the theoretical display resolution limit for all of the possible range scales assuming that the theoretical limit is imposed by the requirement that the targets be separated by at least one pixel to be broken out. The results are included in table VIII.

$$\left(\frac{80\ nm}{6\ in}\right)\left(\frac{1}{75\frac{pixels}{in}}\right)\left(6000\frac{ft}{nm}\right)=1067\frac{ft}{pixel} \qquad (36)$$

Table IX includes all of the theoretical radar and display range resolution calculations and shows which is the limiting factor for the total system performance. As shown, the radar is the limiting factor for all but the case of the Real Beam Mode and the 40 nm display range. Table X repeats the comparison for the theoretical azimuth resolution. In azimuth, the radar is the theoretical limiting factor in resolution for all but the 100 feet separation target and the Real Beam Mode of operation.

As mentioned above, the theoretical resolution was calculated in order to bound the flight test requirements and save test time. Analyzing the two previous tables allows several conclusions to be drawn concerning when the azimuth and range resolution targets could first be broken out on a data run inbound to the resolution array:

In Real Beam Mode Expect:

*In Range:

✓80 to 40 nm no breakouts
✓40 to 20 nm no breakouts
✓20 to 0 nm one breakout

*In Azimuth:

✓80 to 4.4 nm no breakouts
✓4.4 to 2.2 nm two breakouts
✓2.2 to 0 nm four breakouts

In DBS 1&2 Expect:

*In Range:

✓80 to 40 nm...Not Displayed
✓40 to 0 nm two breakouts

*In Azimuth:

✓80 to 40 nm...Not Displayed
✓40 to 22 nm two breakouts
✓22 to 7.3 nm four breakouts
✓7.3 to 0 nm six breakouts in DBS 2 only, due to display resolution

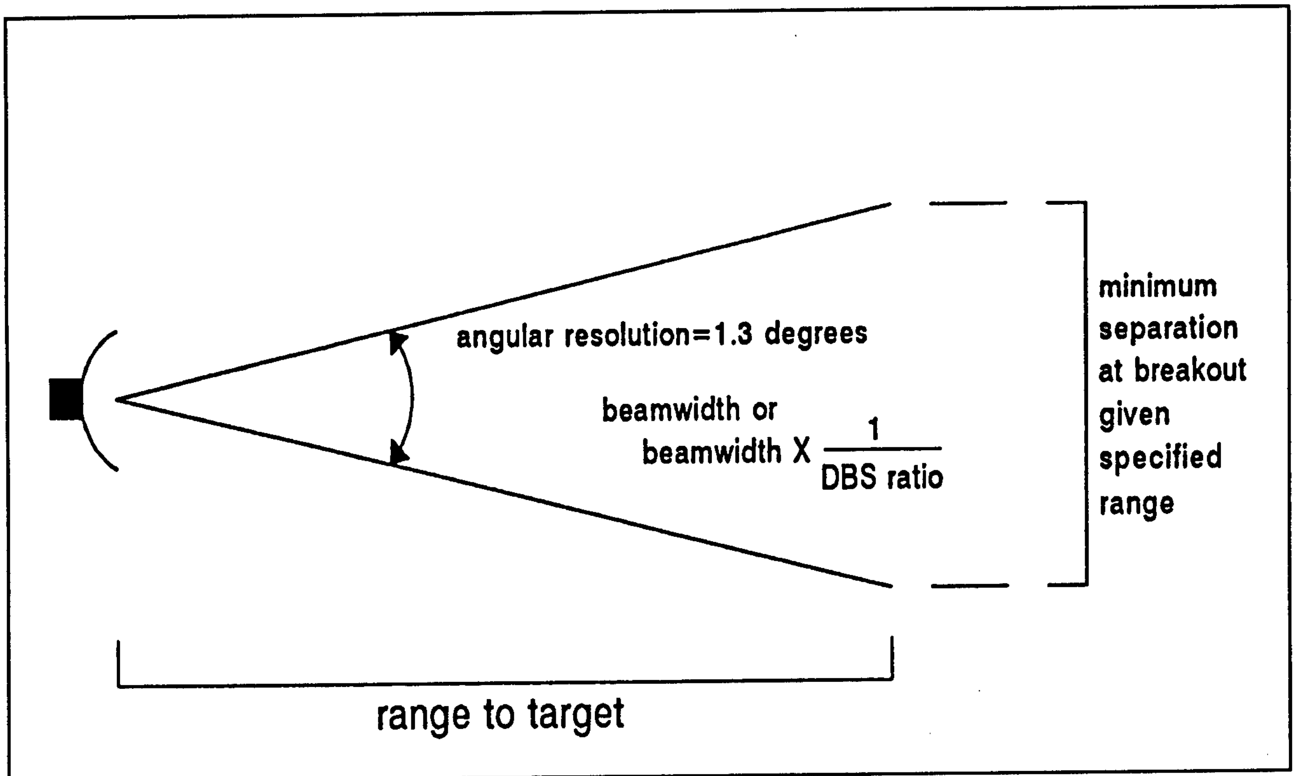


Figure 24: Azimuth Resolution for Targets of Known Separation

Table VII: Theoretical Azimuth Resolution for all Air-to-Ground Radar Modes and all Azimuth Resolution Target Separations

Target Separation	Real Beam Breakout	DBS 1&2 Breakout
600 ft	4.4 nm	44 nm
300 ft	2.2 nm	22 nm
100 ft	0.73 nm	7.3 nm

Notes: (1) DBS 1&2 have the same azimuth resolution since they have the same angular resolution and DBS ratio.
(2) The maximum display range for the DBS modes is 40 nm.

Table VIII: Theoretical Display Resolution

Scale (nm)	Resolution (ft)
80	1067
40	533
20	267
10	133
5	67

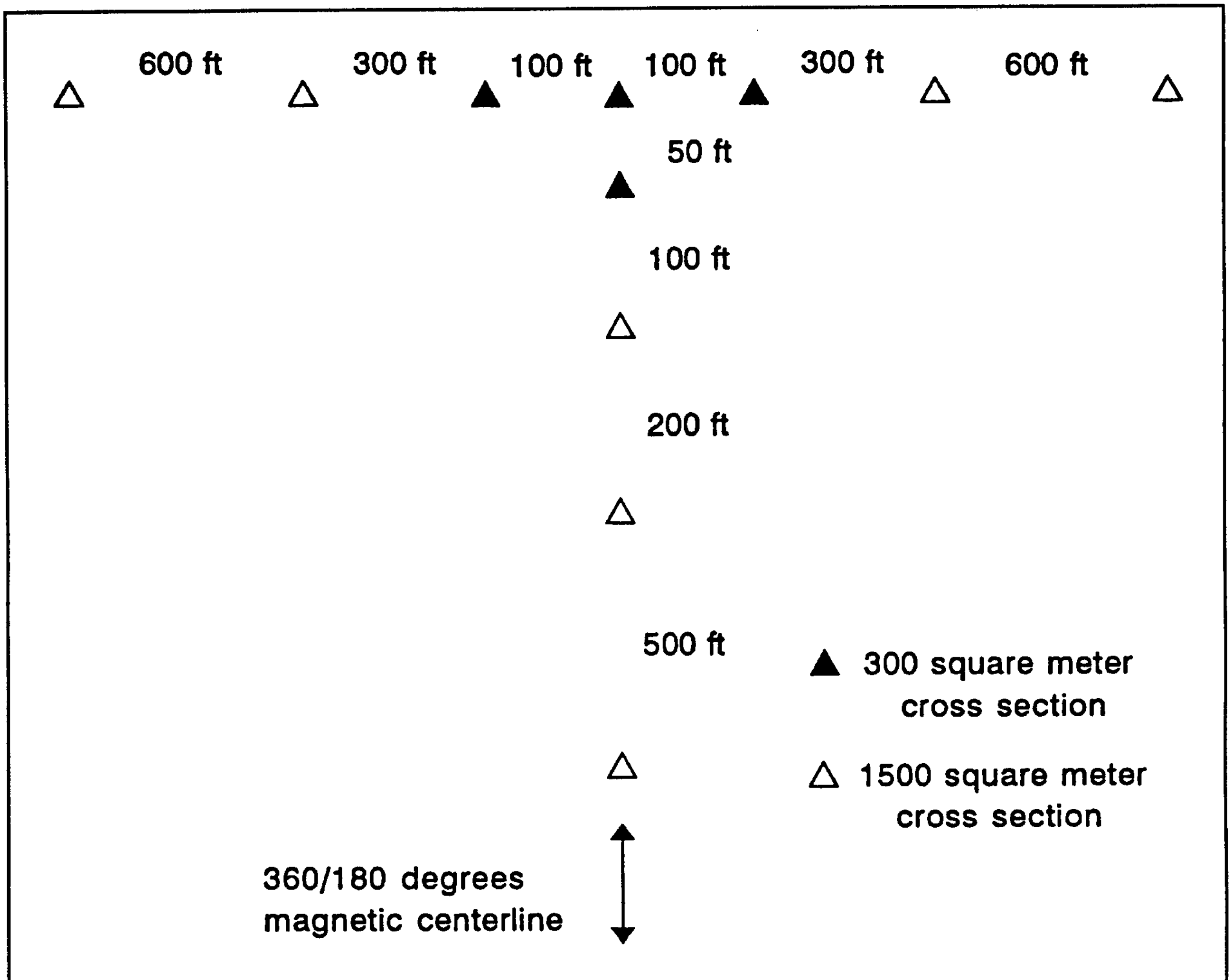


Figure 25: Fictional Air-to-Ground Resolution Array Diagram

Table IX: Comparison of Radar and Display Theoretical Range Resolution

Scale (nm)	Mode	Radar Resolution (ft)	Display Resolution (ft)	Limiting Factor
80	Real Beam	1112	1067	Radar
40	Real Beam	371	533	Display
20	Real Beam	371	267	Radar
10	Real Beam	371	133	Radar
10	DBS 1	148	133	Radar
5	DBS 2	148	67	Radar

Table X: Comparison the Radar and Display Theoretical Azimuth Resolution

Target Separation (ft)	Mode	Target Breakout (nm)	Scale/ Display Resolution (nm/ft)	Limitation
600	Real Beam	4.4	10/133	Radar
300	Real Beam	2.2	10/133	Radar
100	Real Beam	0.73	10/133	Display
600	DBS 1	44	10/133	Radar
300	DBS 1	22	10/133	Radar
100	DBS 1	7.3	10/133	Display
600	DBS 2	44	5/67	Radar
300	DBS 2	22	5/67	Radar
100	DBS 2	7.3	5/67	Radar

Notes: (1) Assumes that the display automatically downscales as the aircraft approaches the target.
(2) The DBS 1&2 radar parameters are the same and so the theoretical radar resolution is the same.

7.2.4. Designing the Test

In general, a radar will never exceed the theoretical limits of resolution as calculated above. Assuming the system was designed to meet the system specification, it is almost certain that the theoretical limits encompass the specification. Bounding the test by the theoretical limits then gives an efficient and sufficient check of the parameter. In this case the theoretical limits provide the maximum reasonable range at which it is necessary to perform each test. Looking at the results listed above, the first array target breakout in the Real Beam Map mode will theoretically occur in range at the edge of the 20 nm display range. The Real Beam Map resolution test will then begin at 20 nm. In the DBS 1&2 modes the theoretical resolution limit predicts that targets will break out in both azimuth and range at the DBS 1&2 maximum operating range of 40 nm and so the DBS 1&2 resolution tests will begin at 40 nm. The test resolution array is presented in figure 27. Due to the flight time constraints, a single data point will be taken per radar mode for a total of three runs inbound to the array.

The reflectors, which make up the sample test resolution array depicted in figure 27 have a 15° horizontal beam width and a 6° vertical beam width within which the test must be performed. Figure 27 is a view looking down upon the array depicting the horizontal beam width limits of the array in terms of the magnetic bearings to and from the array center as well as the array centerline magnetic bearing. As mentioned, figure 28 depicts the vertical beam width limits of the array in terms of aircraft altitude versus range from the array center. The pilot must ensure that the aircraft remains within the airspace defined by the two magnetic bearings from the target shown in figure 27 as well as the range dependent altitude restrictions defined in figure 28. A third restriction is also described in Chapter 2, the DBS mode of operation has a notch over the nose of the aircraft through which the DBS radar detection is not available. As mentioned above, this notch is 7° in width for the sample radar. This means that the pilot can never point the aircraft directly at the array while testing the DBS modes and must "zigzag" inbound to the target within the azimuth limits described above.

In conversation with the test pilot, you determine that 300 KIAS is the best airspeed to perform the test. This airspeed allows for moderate maneuvering while simultaneously performing a descent at a flight path angle of 10° with horizontal. The pilot also mandates a 200 feet AGL minimum altitude for the test as well as VFR conditions. Due to high traffic density in the

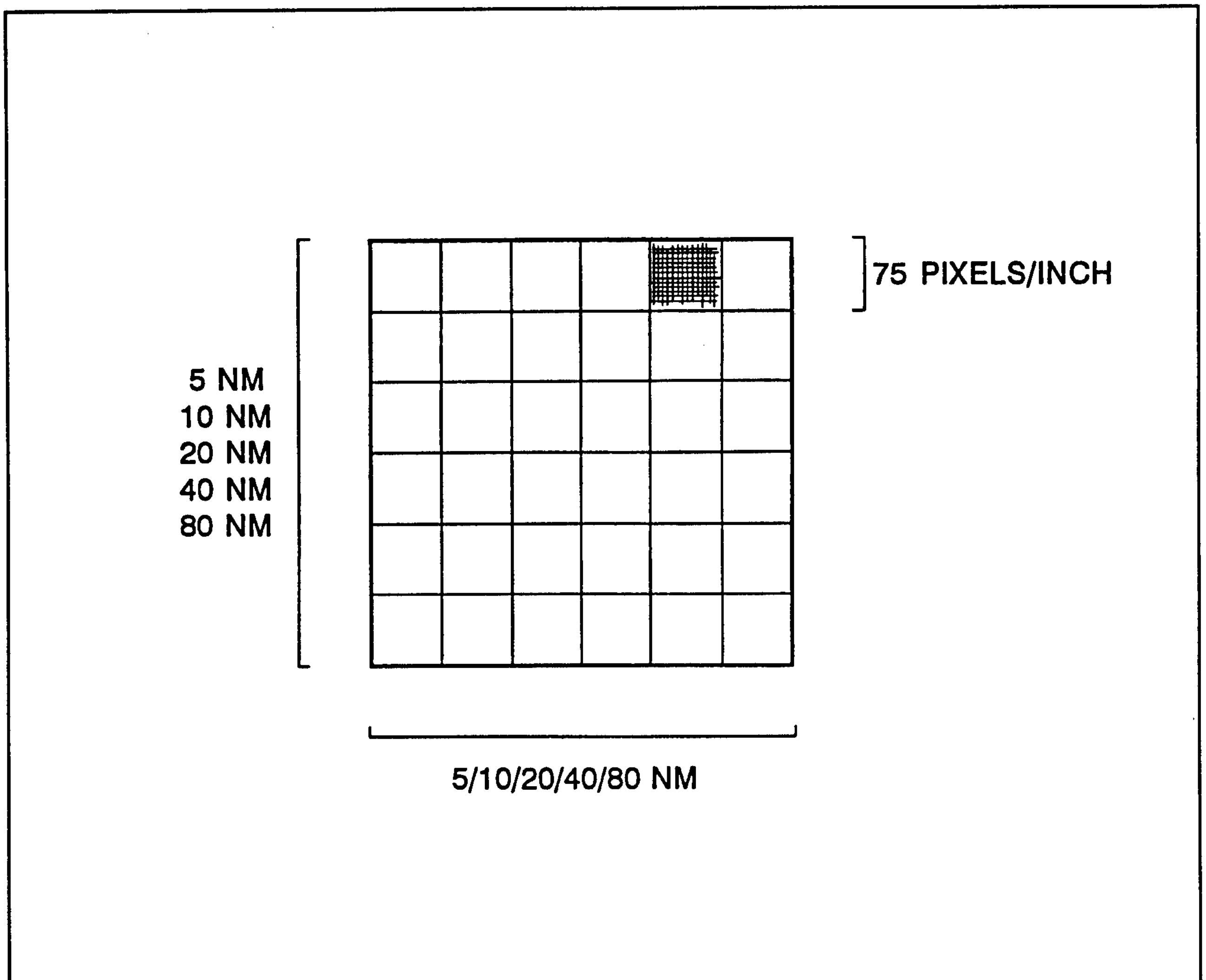


Figure 26: Relationship of Display Dimensions, Scale Sizes and Pixel Grid

working area, he also requires that there be clear visibility for the entire descent to the array, with no cloud layers along the route from the start of the run to the array. The rate of descent in feet per minute will be limited to half the altitude in feet, necessitating a small deviation from the desired flight path angle during the last part of the test, approaching the array. Maneuvering is limited to +3 g and -0.5 g maximums and the pilot in the front seat will act as the pilot at the aircraft controls and will ensure he is looking out of the aircraft for traffic at all times while the pilot in the back seat conducts the test.

Knowing that the vertical centerline of the resolution array is 10° above vertical and that the airspeed over the ground is <u>approximately</u> 6000 feet/nm allows the starting altitude for the data runs beginning at 20 nm and 40 nm from the array to be determined as in equation 37.

$$
\begin{gathered}
ALT = RANGE\,[\tan(10°)] \\
10° = \textit{center of array vertical beamwidth} \\
\textit{at } 20nm: \\
ALT = (20nm)[\tan(10°)]\left(6000\frac{ft}{nm}\right) \qquad (37) \\
ALT = 21{,}200ft \\
\textit{at } 40nm: \\
ALT = 42{,}300ft
\end{gathered}
$$

A 300 KIAS airspeed is approximately 5 nm per minute, requiring 4 minutes to complete the 20 nm data run and 8 minutes to complete the 40 nm data runs. The sample array is at sea level and so at the 20 nm beginning range, the 21,200 feet beginning altitude requires a 12,200 ft/4 min=5300 feet/min rate of descent to make the 10° glideslope. The rate of descent is the same for the 40 nm data run since the glide path angle is the same. As a reminder, the flight

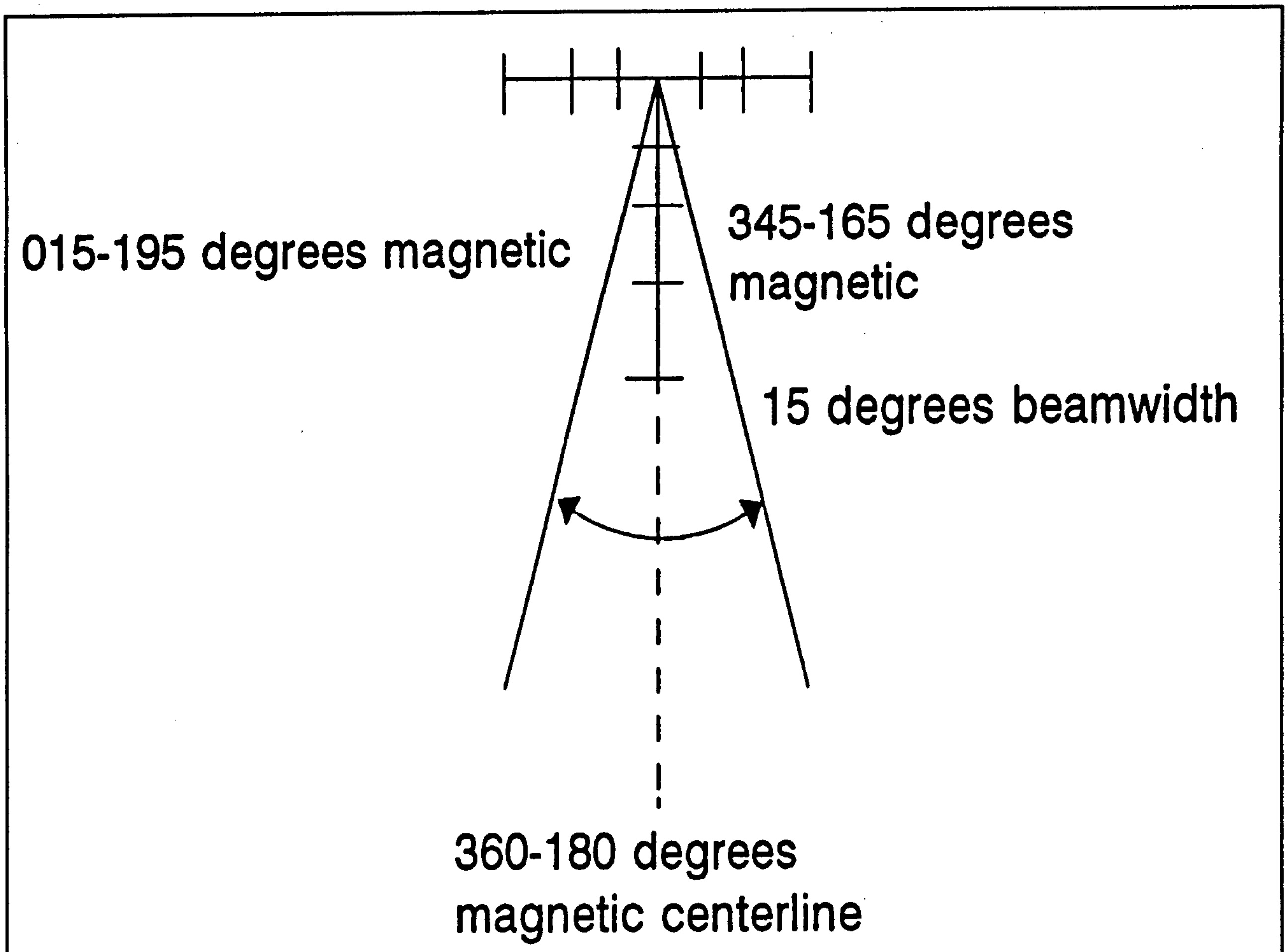


Figure 27: Radar Resolution Array Horizontal Beam Width

path angle will necessarily be deviated from as the rate of descent is shallowed at the lower altitudes and the minimum altitude for the test is approached.

In discussion with the contractor, it is agreed that climb performance data may be taken after takeoff and up to the beginning of the first data run and so the contractor will not begin counting the 30 minutes of flight test time available for resolution measurements until the initial point for the first data run. As outlined above, one 20 nm run and two 40 nm runs are required. Beginning with the 20 nm data point, a single 20 nm inbound run followed by two 40 nm outbound and inbound runs are required for a total of 180 nm. At 5 nm/min, the test will take 36 minutes total, turning the aircraft back over to the contractor over the resolution array at 200 feet AGL. This is 6 minutes? longer than allotted by the contractor; however, after making one last phone call, the contractor agrees to allow the extra 6 minutes.

7.2.5. Data Cards

Cards 75 through 82 are the data cards provided to the project test pilot. Card 1 provides the waypoint definitions to load into the aircraft inertial system to allow quick navigation from the point of aircraft startup (waypoint 0), to the initial point for the 20 nm run (waypoint 1), to the center of the array (waypoint 2) and finally to the initial point for the 40 nm run (waypoint 3). Card 2 is a script for the takeoff and set up for the first data run and card 3 is the data card for the 20 nm data run with the Real Beam Map mode of the radar. Cards 4 through 6 are the script and data cards for the next two runs while cards 7 and 8 depict the horizontal and vertical layout of the array and the flight path requirements. Card 9 is possibly the most important card in that it provides a full page of note taking space for incidental information.

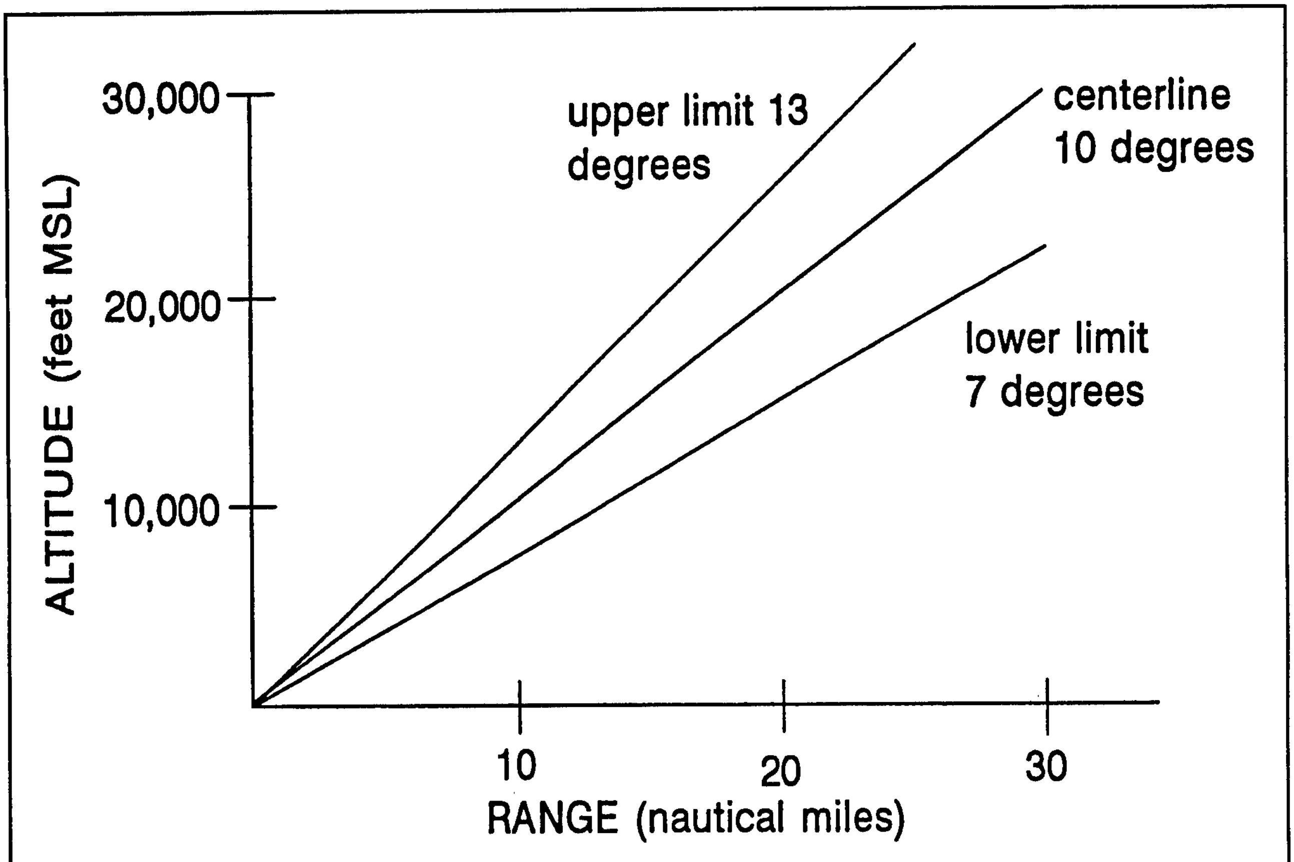


Figure 28: Radar Resolution Array Vertical Beam Width

CARD NUMBER 1

WAYPOINTS

(0) N 38° 00′ W 123° 00′ HOMEPLATE

(1) N 38° xx′ W 123° xx′

(2) N 38° yy′ W 123° yy′

(3) N 38° zz′ w 123° zz′

Card 75: Case Study Data Card 1

DATA CARD 2

F/A-XX RADAR RESOLUTION TEST

-TAKEOFF AND PROCEED TO WP 1

-SET 300 KIAS

-CLIMB TO 21,200 FEET MSL

-CROSS WP 1 INBOUND TO THE ARRAY AT WP 2 HEADING 360°

-SET A 5300 FT/MIN RATE OF DESCENT AND REMAIN IN THE GLIDESLOPE BAND

-PLACE THE RADAR IN THE REAL BEAM MAP MODE, BEGIN IN A 40 NM SCALE

-DESIGNATE THE ARRAY IN THE GEOSTABLE MODE AND EXPECT THE DISPLAY TO AUTO DOWNSCALE

-KEEP THE ARRAY WITHIN 353° -007°

-OBSERVE A MINIMUM ALTITUDE OF 200 FEET AGL

-OVERHEAD THE TARGET, TURN OUTBOUND TO WP 3

Card 76: Case Study Data Card 2

DATA CARD 3

RUN NUMBER 1

REAL BEAM MODE

MAX NUMBER OF RANGE TARGETS	RANGE AT TARGET BREAKOUTS		
	2	4	6

NOTES:

Card 77: Case Study Data Card 3

DATA CARD 4

-CLIMB TO 42,300 FEET MSL

-CROSS WP 3 INBOUND TO THE TARGET, WP 2, HEADING 360°

-SET 5300 FT/MIN RATE OF DESCENT AND REMAIN IN THE GLIDE SLOPE BAND

-SET THE RADAR TO DBS 1 MODE

-DESIGNATE THE ARRAY USING THE GEOSTABLE MODE

-KEEP THE ARRAY WITHIN 353° TO 007°

-KEEP THE ARRAY OUT OF THE NOTCH

-OBSERVE A MINIMUM ALTITUDE OF 200 FEET AGL

-OVERHEAD THE TARGET TURN OUTBOUND TO WP 3

-REPEAT IN THE DBS 2 MODE

Card 78: Case Study Card 4

DATA CARD 5

RUN NUMBER 2

DBS 1 MODE

MAX NUMBER OF RANGE TARGETS	RANGE AT TARGET BREAKOUTS		
	2	4	6

NOTES:

Card 79: Case Study Card 5

DATA CARD 6

RUN NUMBER 3

DBS 2 MODE

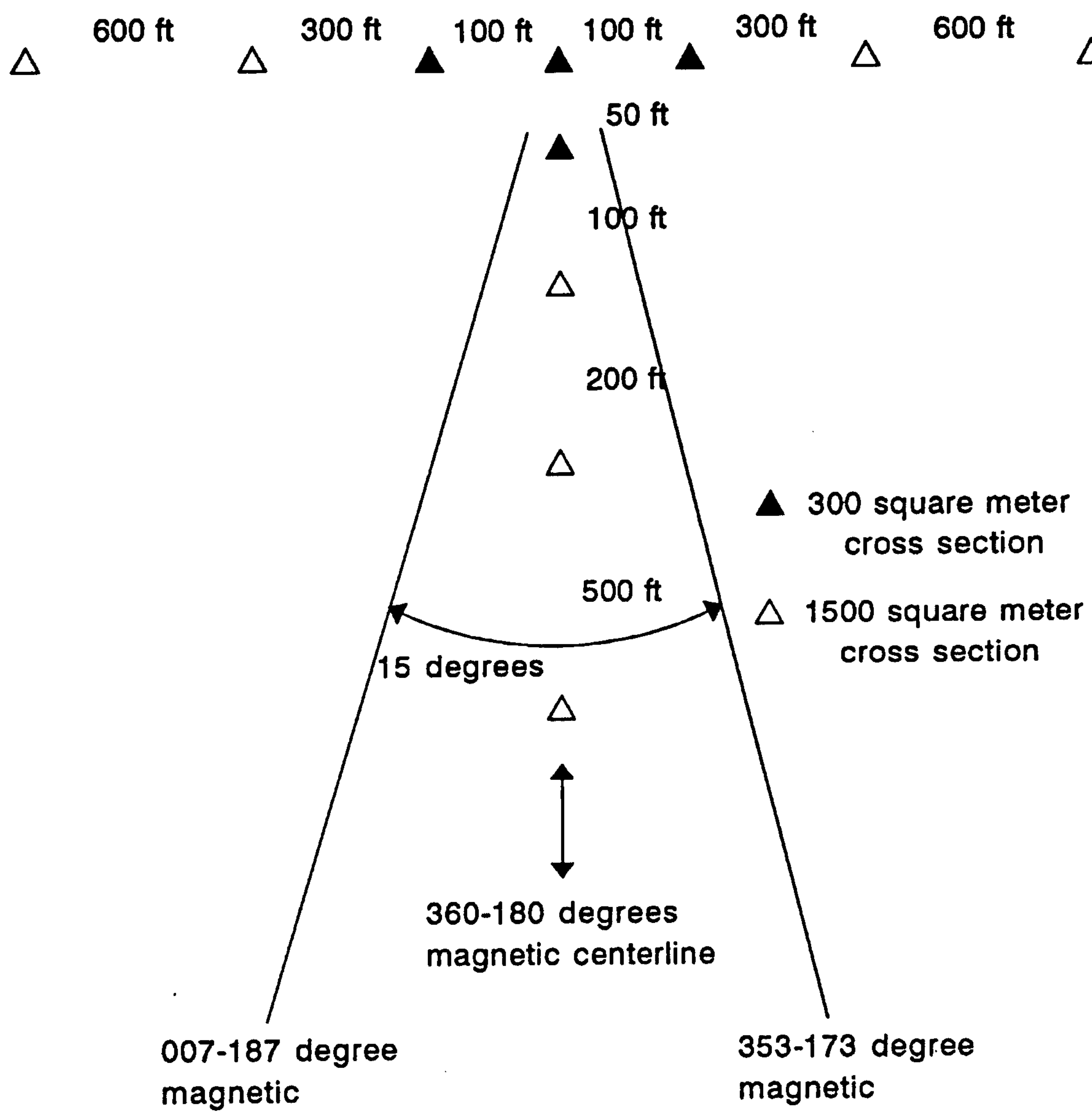
MAX NUMBER OF RANGE TARGETS	RANGE AT TARGET BREAKOUTS		
	2	4	6

NOTES:

Card 80: Case Study Card 6

CARD NUMBER 7

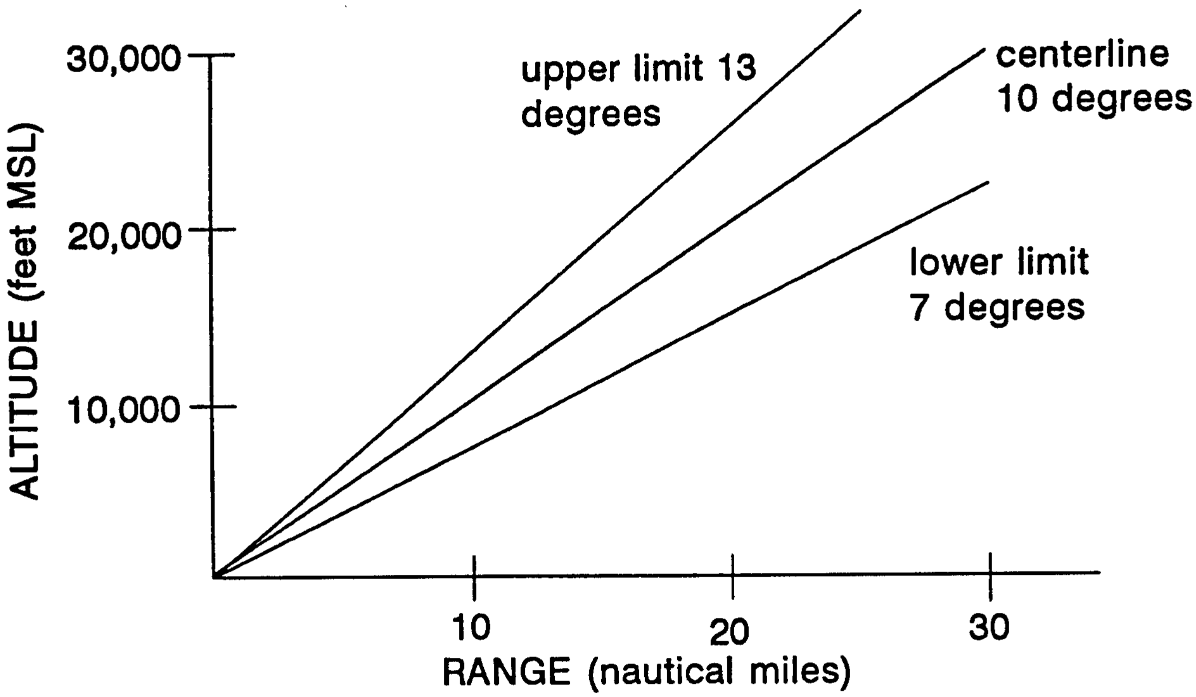
ARRAY DIAGRAM



Card 81: Case Study Card 7

DATA CARD 8

ALTITUDE BAND



$5300 \frac{FT}{MIN}$; 300 *KIAS*
ON GLIDESLOPE
$\gamma = 10°$

Card 82: Case Study Card 8

7.2.6. Summary

This case study has demonstrated a couple of important points. First, the simple techniques described in the previous sections are useful for real world application and are adequate for a wide range of quick measurements. What some of the tests lack in precision and documentation, they make up in accessibility and ease of implementation. Adding more instrumentation and complexity to the test changes the basic technique very little and merely enhances the data collection process with automatic and sometimes more precise data. Second, the case study demonstrated the criticality of fully understanding the workings of the system under test. Without a thorough knowledge of the theoretical resolution limits of the radar under test, it may have been necessary to test the resolution out to the display limits of the radar, wasting flight time and thus money.

8.0. CONCLUSIONS AND RECOMMENDATIONS

These test techniques should be used as a generalized baseline for the development of specialized tests for new systems. A basic knowledge of system theory and the characteristics of the test article are assumed. All the techniques presented are as simple as possible and require a minimum of outside assets. Better and more exact methods exist; however, most merely involve scaling up the techniques presented here, usually in the form of more sophisticated and precise truth data (time/space positioning data, telemetry, onboard instrumentation, etc.). Using the methods presented here, the test pilot should be able, in just a few flights, to make a good qualitative assessment of the system under test and have adequate numerical data to support his or her assessment. Although not suitable in some test programs, this level of data accuracy is often sufficient. More important than the exact test procedure presented, is the methodical, common sense thought process required for test planning. Understanding the development of the simple tests presented here for the sample systems will enable the evaluator to develop his or her own procedures for systems and functions not covered by this document.

During the development of the techniques presented here, frequent license was permitted in the selection of test ranges, speeds, altitudes, etc. It cannot be overemphasized that the details of the test must be specific to the needs of the system and platform under test. It is intended that the numbers presented will give the reader a flavor for the requirements of the fictitious sample systems and platforms, enabling him or her to then choose test points and conditions for other systems. One final point must be stressed. Every detail of each individual test, as well as the order and precedence, must be thought through and planned before the flight and then the plan must be flown, if usable data is to be consistently obtained.